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The Influence of Ship Deck-Edge Lighting on Perception of Position and Movement During Helicopter Recovery

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ABSTRACT

Accurate perception of position and self-movement is a critical factor for many tasks in aviation; particularly low-level flight, take off and landing. An especially demanding task of this kind is that of deck landings for rotary-wing aircraft, which are often conducted during the night. During night operations, ship-based lighting is used to assist the aircrew and flight-deck staff in the conduct of take-off and landing. While reasonably effective, the lighting systems currently employed by the Royal Australian Navy (RAN) were not designed specifically with the aim of enhancing aircrew visual perception. In two experiments a deck-edge light (DEL) system which provides a richer visual cueing environment for the aircrew than traditional point-source lighting systems was investigated in terms of its potential benefits for aircrew visual perception. These experiments could reveal no clear performance advantage for DELs over standard point-source lights. In both experiments, participants were asked to make ratings of their confidence in their judgments. Only a very weak relationship was found between accuracy and confidence, suggesting that care should be exercised when subjective ratings are interpreted in place of performance data. Further investigation is required in order to understand the potential of DEL systems for enhancing the safety of night operations.

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The Influence of Ship Deck-Edge Lighting on Perception of Position and Movement During Helicopter Approach to Recovery

Executive Summary

The UK's Royal Navy have trialled a system of Deck-Edge Lights (DELs) designed with the specific aim of supporting enhanced aircrew visual perception and performance during night operations, in particular when recovering to a ship. This system comprised an assembly of electro-luminescent panels (ELPs) positioned around the edges of the ship's flight deck and hangar. Subjective ratings collected from aircrew during evaluations of the system conducted by British researchers were suggestive of a wide range of benefits from the use of this system for perception of one's own position and motion relative to the ship. However, no data of the kind usually associated with experimental investigations of human perceptual performance was reported. In the absence of such data it remained unclear whether the ratings provided by aircrew were based on real improvements in their perceptual performance and if so, what aspects of aircrew visual perception were actually enhanced by the DELs.

Two experiments on the potential benefits of the DEL system are reported here. These experiments extend on earlier research by applying standard techniques from experimental psychology to achieve a clearer understanding of perceptual performance on tasks associated with recovering to a ship. Results obtained from these experiments have failed to demonstrate any clear performance benefit of the DEL system over a more traditional point-light system in terms of perception of rate of approach (Experiment 1) or relative bearing (Experiment 2). What's more, the relationship between performance and ratings of confidence in performance has been found to be very weak. This indicates that participants had little insight into their own perceptual performance and that extreme caution should be exercised when interpreting subjective ratings in place of data more directly related to perceptual functioning. Given these findings, it is possible that the positive subjective evaluations given the DEL system by British aircrew may have resulted from that lighting system simply being visible at greater distances from the ship (allowing earlier adjustments to their approach), or because the DEL system appeared novel. It remains possible, however, that aspects of aircrew visual perception not investigated here (e.g., perception of direction of self-movement or perception of ship motion) were enhanced by the DELs, or that differences between the particular lighting systems used in earlier research and those simulated here led to discrepancies in the findings. Further investigation is required in order to understand the potential of DEL systems for enhancing the safety of night operations.

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1. Introduction

Accurate perception of position and self-movement is a critical factor for many tasks in aviation; particularly those which require navigation close to terrain or other structures. This includes low-level flight, take off and landing. An especially demanding task of this class is that of deck landings for rotary-wing aircraft. Faced with the task of landing on a ship at sea (henceforth *recovering* to the ship), the pilot must accurately perceive the position and relative motion between his/her aircraft and the ship's flight deck and regulate these with a great degree of accuracy. The relative motion which must be accurately perceived and regulated by the pilot is usually comprised of multiple translatory and rotational components making this a difficult, high-workload and high-risk perceptual control task.

While factors such as weather, sea state and operational tempo may give rise to variability in the way that recoveries are conducted, the task can generally be thought of as consisting of two major phases; (i) the approach phase, and (ii) the hover and landing phase. During the approach phase of the recovery, the pilot must fly a decelerating, descending path along a roughly 3 deg glide slope from directly behind the ship to come to station either over, or just behind the flight deck. During the hover and landing phase the pilot must manoeuvre his/her aircraft over the flight deck and, allowing for the pitching and rolling movements of the ship, land without severe impact. Because of the characteristic differences between the two phases, different demands are placed on the pilot's perceptual and motor abilities at different times during the recovery. The primary tasks during the approach phase are location of the ship and regulation of the aircraft's deceleration and descent. The primary tasks during the landing phase are perception of the pitching and rolling of the ship and control of the position of the helicopter over the flight deck.

While recovery to a ship at sea is always one of the most demanding tasks a pilot can attempt there are factors which can exacerbate that difficulty. Important among these is the conduct of operations at night. In low-light conditions the visual information available to the aircrew for guiding their aircraft in the vicinity of the ship is reduced. This problem can be partially remedied through the use of night-vision goggles (NVGs) which amplify ambient light. However, by themselves, these devices ought not be considered a straightforward or complete solution to the problem of conducting night operations safely (see Zalevski, Meehan, & Hughes, 2001 for an example of problems introduced by the use of NVGs). Additional strategies aimed at enhancing aircrew visual perception during embarked night operations are therefore of ongoing interest and importance.

1.1 Deck Edge Lighting

During night operations, ship-based lighting is used to assist the aircrew and flight-deck staff in the conduct of take-off and landing procedures. The lighting systems currently employed by the Royal Australian Navy (RAN) consist of various indicators (e.g., glide path indicator, stabilised horizon bar) and an arrangement of point-source lights, some of which cast light away from the ship and some of which cast light onto the surfaces of the ship's hangar and flight deck in order to illuminate them. While such lighting systems are reasonably effective and flexible, they present a quite significantly impoverished visual

cueing environment relative to daytime operations and they have undergone little development over recent times. It is therefore possible that different lighting systems, designed with aircrew visual perception in mind, could be advantageous.

An alternative lighting system, designed with the specific aim of supporting enhanced aircrew visual perception and performance was investigated by the British Defence Research Agency (DRA, now QinetiQ; Tate, 1994, 1995). This system consisted of an arrangement of Electro-Luminescent Panels (ELPs) positioned around the edges of the ship's flight deck and hangar (see Figure 1).

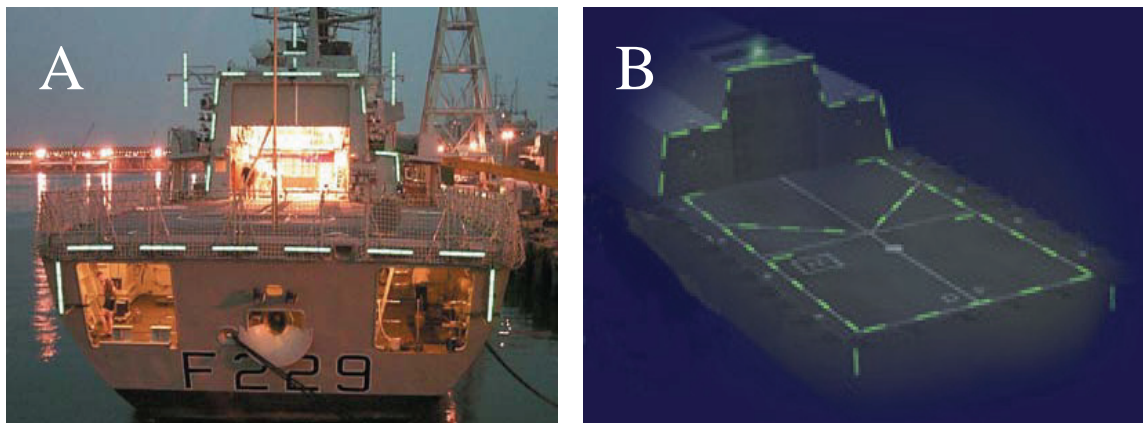


Figure 1. British Deck-Edge Lighting (DEL) system consisting of an arrangement of electro-luminescent panels (ELPs) positioned so as to provide a stippled outline of the ship's flight deck and hangar. Panel A shows the system installed on a British frigate, while Panel B shows a simulated pilots-eye-view of the system.

This deck-edge light (DEL) system provides a much richer visual cueing environment for the aircrew than traditional point-source lighting systems. Sources of visual information specifying the size, shape and boundaries of the flight deck and hangar (including linear perspective, relative size, and compression gradients) are readily visible. In both simulator and flight trials conducted by DRA, subjective ratings obtained from aircrew indicated an advantage for the DEL system over traditional systems. Reports from British aircrew were indicative of a wide range of benefits from the use of DELs for both perception of ship aspect and motion and perception of self motion in terms of angle, altitude and rate of approach towards the ship. In summarising the effectiveness of DELs for night operations Tate wrote that aircrew were "immediately aware of the ease in which they could assess position, attitude and rate cues" when using DELs, and that "pilots unanimously considered that adoption of ELP lighting (DELs) could have a significant impact on operational limits for night deck operations" (Tate, 1995, p. 254).

Given the favourable reports provided by British aircrew it is possible that DELs may represent a beneficial addition to the RAN's infrastructure supporting embarked night operations. However, four significant and related shortcomings of the British research were that; (i) the impressions of aircrew gained through subjective rating scales and post-trial interviews were only thinly supplemented by more objective performance data, (ii) objective variables that were recorded (landing scatter and vertical velocity at landing)

failed to yield results that were clearly favourable for the DELs, (iii) objective variables were related only to one part of the recovery task (i.e., the landing, but not the approach) and (iv) no controlled experimentation was conducted to confirm subjective reports of the wide-ranging perceptual benefits of DELs.

Data from controlled experiments examining perceptual performance during the recovery could pinpoint what real perceptual benefits (if any) the DELs actually bestowed. And importantly, such data would not be subject to the potential influence of novelty, which may have skewed aircrew evaluations of the DEL system in a positive direction during previous research. In the absence of these data it remains unclear whether the positive statements reported previously are based on real improvements in aircrew performance and if so, exactly what factors drove those improvements.

Two experiments aimed at furnishing these data are reported here. The first experiment investigated potential advantages of the DELs for perception of rate of closure during approach. The second experiment investigated potential advantages of the DELs for perception of approach angle/ship aspect. The details of each experiment are reported in turn, following an outline of the general methods below.

2. General Methods

In order to determine whether a system of DELs is likely to confer any perceptual advantage in terms of perceiving position and rate of approach during night recoveries, two PC-based psychophysical¹ experiments were conducted as detailed below.

2.1 Apparatus and Stimuli

The experimental apparatus consisted of a Windows PC, a CRT monitor and chinrest. The PC was an Intel Pentium IV-based computer running at 2.0GHz, with a Matrox Millennium G450 32MB AGP video card. This was used to generate stimuli and present them on a 21-inch Barco colour CRT monitor running at 1024 x 768 x 60Hz. Participants viewed the stimuli using a chinrest from a distance of 41.2cm. From this distance the monitor subtended 40deg visual angle in the vertical dimension. This is approximately equal to the field of view afforded by current-generation NVGs. Because of the aspect ratio of the monitor the field of view in the horizontal dimension was slightly larger, at 53.3deg.

Images were generated using OpenGL and GLUT libraries in a C++ programming environment and were rendered in real time. The stimuli presented a first-person view of a virtual environment. The scene was drawn in green to approximate NVG-like conditions. No attempt was made to faithfully represent NVG optics in the stimuli nor to accurately model the physics of the aircraft. However, importantly, static and dynamic properties of the geometry of the visual scene were veridical for the viewing position of

¹ The term 'psychophysics' was first coined by Fechner (1860; cited in Sekuler & Blake, 1994) and refers to a branch of experimental psychology in which standardised methods are used to determine the relationship between physical properties of a stimulus array and the perceiver's experiences of these properties.

the participant. In this sense the stimuli were similar to those used over many years in experimental investigations of human perception of spatial layout and motion (e.g., Best, Day, & Crassini, 2003; Cutting, 1986; DeLucia, 1991; Kaiser & Hecht, 1995; Royden, Banks, & Crowell, 1992; Stone & Perrone, 1997; Vincent & Regan, 1997; Warren, 1976). Four basic kinds of scenes were drawn. In so-called 'high visibility' conditions stimuli consisted of a pilots-eye view of the sea surface, a CAD model of a ship (a RAN FFG frigate), and ship lighting. In so-called 'low visibility' conditions the sea surface and ship model were not visible; only the ship's lighting could be seen. In each condition, the lighting configuration on the ship could take one of two forms. In 'standard' lighting conditions a point-source lighting configuration was drawn, while in 'DEL' conditions a system of DELs was drawn. The lighting systems depicted in the experiment were designed to be representative of operational systems. While any particular operational system may differ slightly from those used in the experiment, the perceptual cueing afforded by operational point-light and DEL systems (and any differences between such systems) is likely to be substantially similar to those used here. The four conditions formed by factorial combination of visibility and lighting as described above constituted the four basic kinds of scenes that were included in the experiments. These four kinds of scenes are depicted in Figure 2.

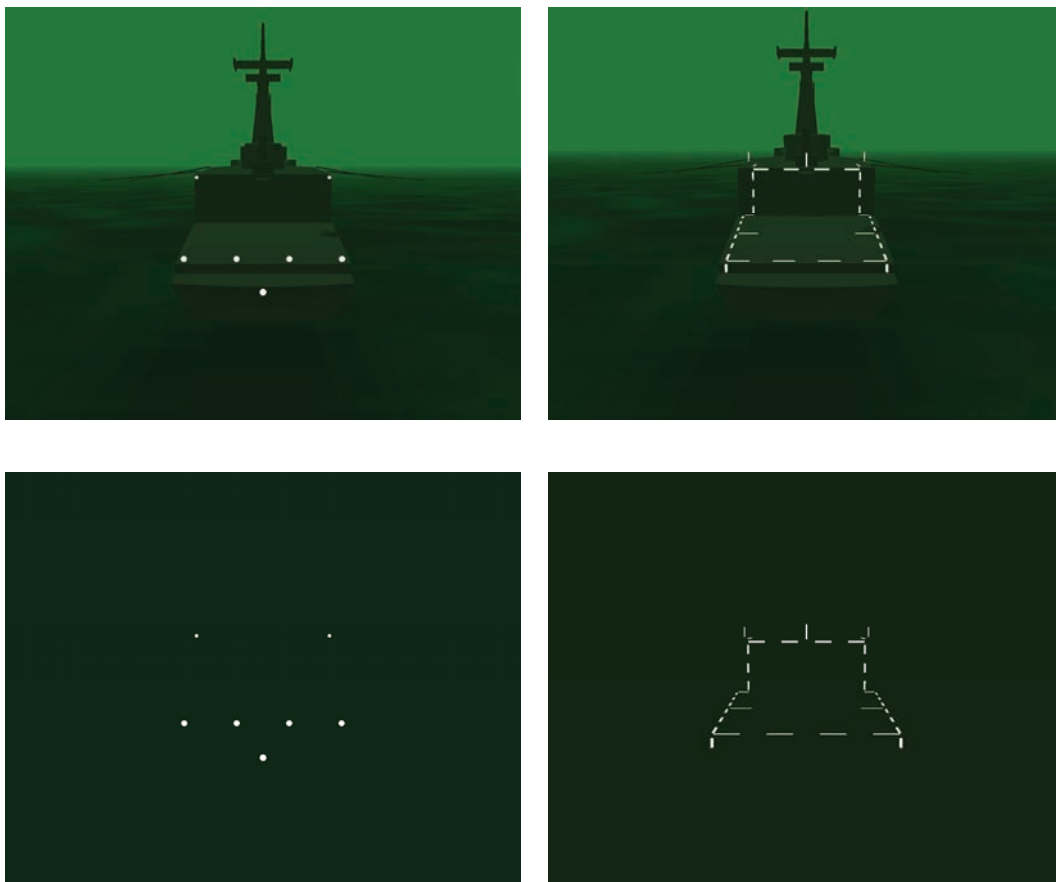


Figure 2. Screen captures of the four basic viewing conditions included in the experiment. The upper panels depict the high visibility condition, the lower panels the low visibility condition. The left-hand panels depict the point light condition, the right-hand panels the DEL condition.

3. Experiment 1: Perception of Self-Motion During Approach

The first experiment was motivated by aircrew evaluations cited in the reports mentioned above, and by assessments made by RAN aircrew of NVGs for embarked night operations involving the S-70B-2 Seahawk aircraft. Smallhorn & Matthews (2000) reported the results of RAN trials involving night recoveries using NVGs and a standard, point-source ship lighting system. Among other findings, these authors reported that when using NVGs “appreciation of closure rate during final approach was not obvious visually ... The image of the ship appeared to quite suddenly appear close at the later stage of the final approach having received limited visual cues to the rate of closure between aircraft and ship during the earlier stages of the approach” and that this made necessary “large uncomfortable nose up attitudes of up to 10-15deg to arrest the closure.” (p.20). As indicated earlier, one of the key tasks for the approach phase of recovery is the regulation of self-movement to fly a smoothly decelerating, descending approach towards the ship. The comments by Smallhorn and Matthews suggest that a lack of salient visual cues impeded the aircrew in their task of regulating deceleration. These authors regarded the problems with perception of rate of closure as an unsatisfactory deficiency of the NVG plus standard lighting combination. Importantly, one of the benefits of the DEL system highlighted by British crews in the research reported earlier was enhanced perception of “rate of closure” during approach (Tate, 1994, 1995). British crews reported that the DEL system enabled them to better perceive and control the velocity of their self-movement towards the ship than a standard lighting configuration, either “with or without NVGs” (Tate, 1994, p.10).

The perceptual task of visually controlling braking during approach towards a target has most often been conceptualised as one of perceiving and regulating time-to-contact (TTC; e.g., Lee, 1976; Lee & Reddish, 1981; Tresilian, 1991; Warren, 1995). When an observer and object close on one another, the image of the object dilates on the observer’s retina according to an accelerating function. A schematic representation of this dilation is presented in Figure 3. An object (black bar) is depicted approaching an eye in the direction indicated by the large, leftward-pointing arrow. The top left panel shows the relative position of the eye and object and the visual angle subtended by the object (θ_1) at Time 1. The bottom left panel shows the relative position of the eye and object and the visual angle subtended by the object (θ_2) at Time 2. Note that the visual angle subtended by the object at Time 2, when it is closer, is appreciably larger than that at Time 1, when it is farther away. For an object approaching at a constant rate this increase in retinal image size follows an accelerating function, with the greatest change in size occurring when the object is relatively close to the observer. The change that takes place in distance and retinal image size during such an approach is depicted by the plot in the right-hand panel of Figure 3.

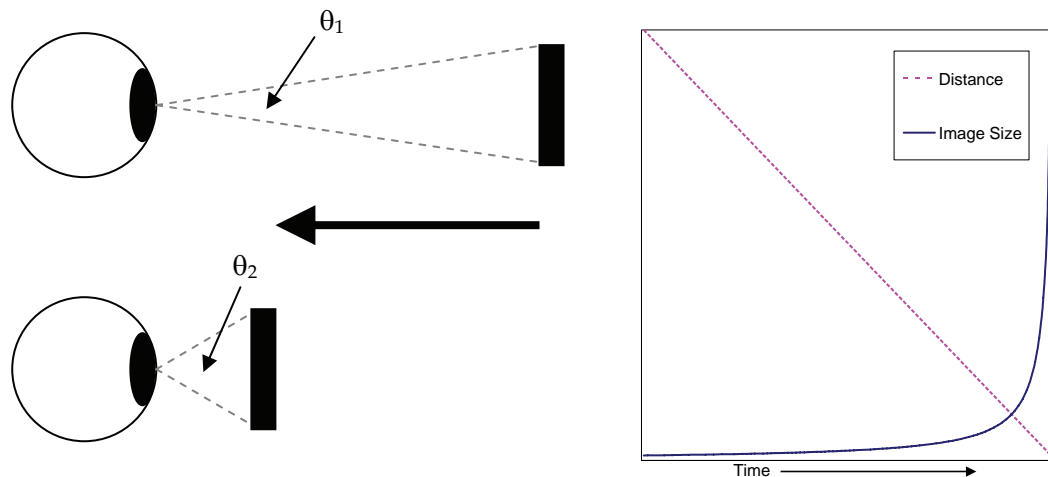


Figure 3. Schematic representation of the change in retinal image size that takes place when an object-observer pair close on one another (i.e., object approaches observer's point of view or vice versa).

Lee (e.g., 1976) showed that TTC could be perceived directly from a property of this retinal image expansion which he called *tau*. Specifically, *tau* is the ratio of the instantaneous size of the retinal image of a target to the rate of change in the size of that image. The time to contact of an observer moving at constant velocity with an obstacle (itself either moving or stationary) is specified by *tau*. In its simplest form, the use of *tau* for timing braking behaviours is constrained by the fact that it only specifies TTC when relative velocity remains constant. This is a problem for the theory, since most real-world approach behaviours involve changing (often decreasing) velocity. Under conditions of changing velocity, *tau* itself does not accurately specify TTC. However, the first derivative of *tau*, known as *tau-dot* has been shown to be useful in these circumstances (Lee, 1976; Kim, Turvey, & Carello, 1993; Yilmaz & Warren, 1995). During deceleration (e.g., as in approach to recovery) the optic invariant *tau-dot* specifies whether the velocity of self-motion will reach zero (i) before reaching the target, (ii) at the location of the target, or (iii) after passing the target. The former case indicates that braking is sufficient to ensure a 'good' stop some distance from the target, while the latter two cases involve so-called 'soft contact' with the target and 'hard contact' or 'crashing' respectively.

Research into the timing of braking behaviours has demonstrated the usefulness of optical expansion information. However, this research has also shown that human observers are likely to use additional perceptual cues. Importantly for the consideration of the usefulness of DELs during approach to recovery are the findings of DeLucia and her colleagues on the role of information specifying layout (e.g., DeLucia, 1991, 1995; DeLucia & Warren, 1994; DeLucia, Tresilian, & Meyer, 2000) and Regan and his colleagues on the role of visual texture information (Gray & Regan, 1999; Vincent & Regan, 1997) in perception of TTC.

In a series of experiments, DeLucia and her colleagues have shown that sources of information specifying the layout of the environment have a role in determining perceived

TTC when they are available. For example, DeLucia (1991) has shown that two sources of information specifying layout in depth – relative size and ground intercept – influenced judged TTC when they were included in displays. Small, near objects appeared to hit after large, far objects, even though optical expansion (accurately) specified the reverse. When the objects were shown to intersect with a textured ground plane (providing veridical information about their position in depth via a gradient of compression), this effect was substantially diminished. DeLucia et al (2000) provided further evidence for the influence of perceived layout on perceived TTC. Using an illusory figure (the Sander parallelogram) these authors demonstrated that misperceptions of spatial layout – in the Sander figure, a misperception of the extent or distance between two points – affects judged TTC, even though motion information remains veridical. These findings are relevant for approach to recovery during night operations because the DEL system depicted in Figure 1 makes information about the size, layout, and shape of structures on the ship more salient than a point-source lighting system. In particular, the extent of the horizontal surface in front of the hangar (i.e., the flight deck) is more clearly specified as is the size of the hangar itself. The implication of DeLucia's findings is that it may be possible to enhance perception of TTC during recovery by making such information available to observers.

Another potential benefit of the DEL system for approach to recovery at night was highlighted by the work of Regan and his colleagues (Gray & Regan, 1999; Vincent & Regan, 1997). These authors showed that the expansion of texture elements on the surface of an object (like the mortar and brick pattern on a wall, or the wood grain on a closed door) could influence perceived TTC with the object. They reasoned from their data that perceived TTC is driven by mechanisms which average across many visual expansion 'signals' corresponding to the expanding retinal images of texture elements on the surface of target objects, as well as the overall expansion of the image of the object itself. The implication of the work by Regan and colleagues is that, like layout information, visual texture may have a role in perception of TTC when it is available.

However, the generalisation of the findings outlined above to the situation of night-time recoveries is not straightforward. Both DeLucia et al's and Regan et al's findings were obtained in experiments in which self-movement was simulated at a constant-velocity. The observer's task was to judge TTC with an object, or to judge which of two objects would impact first when objects or the observer were moving at constant velocity. As previously mentioned, this is not representative of a majority of real-world situations in which braking behaviours are critical; including approach to recovery during helicopter night operations. More relevant to such situations are approaches in which self-movement decelerates and the observer's task is to perceive the adequacy of deceleration. In the former situation, the relevant information is the optical invariant *tau*, while in the latter, the relevant information is the derivative of *tau* called *tau-dot*. While it is possible that DeLucia et al's and Regan et al's findings about the importance of multiple sources of information for timing braking behaviours generalise to the entire class of such tasks, this requires empirical verification.

Relatively few researchers have considered decelerating approaches (Andersen, Cisneros, Atchley, & Saidpour, 1999; Bootsma & Craig, 2003). However, in research which has examined this situation, evidence suggests that, like in the constant velocity case, optical expansion is likely to be supplemented by other information. Andersen et al and Bootsma

and Craig found that *tau-dot* accounted for a large proportion of the variance in collision judgments during decelerating approaches. However, Andersen et al also examined the effect of other sources of information. These authors reported that collision judgments during decelerating approaches were influenced by information of the kind highlighted in the constant-velocity context, such as obstacle size and ground texture. In addition, the variables of velocity (as opposed to deceleration) and distance appeared to play a role in that participants tended to judge deceleration to be insufficient to stop their forward motion before reaching a target if displays contained relatively fast initial velocity or if displays blacked out relatively near to the target.

In summary, it has been shown that there is information in the expansion of the retinal images of objects for perceiving TTC and regulating one's braking when approaching those objects; abilities that are critically important for helicopter deck landings. However, it is also possible that information other than the optical expansion of the object's retinal image may play a role. In regard to DELs, (i) the additional information specifying the layout, size and shape of familiar structures on the ship, and (ii) the additional visual texture information provided by DELs may confer a performance advantage for perception of TTC and visual-guidance tasks based on TTC. However, given the constant-velocity conditions of earlier research, it is unclear whether any such performance benefit should be expected on the specific task of perceiving the adequacy of braking during approach to recovery. Experiment 1 described below was designed to investigate this possibility.

3.1 Method

3.1.1 Participants

The main group of participants was comprised of 10 adult staff members of Air Operations Division, DSTO, Melbourne. This group consisted of seven males and three females, all of whom were considered non-experts in the fields of rotary-wing aviation and deck landing. One member of this group was a qualified civilian fixed-wing pilot. In addition to this group, one expert participant took part in the experiment. The expert participant was a senior RAN aviator with extensive rotary-wing and deck-landing experience. Both expert and non-expert participants had normal or corrected-to-normal vision. Data from the non-expert participants were analysed as a group. Data from the expert participant were analysed separately as a case study to examine whether experience with the task being simulated was likely to yield systematically different responses to those obtained from the general population.

3.1.2 Procedure

Participants viewed stimuli consisting of visual simulation of approach to recovery. As described above and depicted in Figure 2 four conditions formed by factorial combination of visibility and lighting were included in the experiment.

Each trial consisted of a period of simulated forward self-movement, depicting approach towards the ship from directly behind. In all conditions, the self movement began at a simulated distance of 350m from the aft end of the ship's flight deck. During each trial the

point-of-view descended and decelerated in a linear fashion (i.e., at a constant rate of change in velocity) along a 3 deg glide slope which, if continued, would intersect the centre of the top edge of the hangar. However, the view was always blacked out before reaching the ship. The participant's task was twofold: First, they were asked to watch the motion sequence. Second, when the view was blacked out, they were asked to make two responses: First to judge whether the seen rate of deceleration was sufficient, if continued, to stop their movement before reaching the ship (a so-called 'good stop') or whether it would result in the point of view reaching or going past the ship (a so-called 'collision'). Second to provide a rating of their confidence in their collision judgment on a scale of 1-5 (1 = not confident at all, 5 = extremely confident). Both responses were provided via button press and were recorded electronically for later analysis.

To facilitate examination of the Smallhorn and Matthews' (2000) concern about difficulty in perceiving velocity and regulating braking early in the approach, the point-of-view was blacked out either 100m or 50m from the aft end of the flight deck on different trials. The inclusion of deceleration in stimuli such as these leads to the problem of confounding approach outcome and trial time. The problem is that for any given initial speed and distance, to achieve a 'good stop', the simulated movement must decelerate more rapidly than to achieve a 'collision'. This means that during 'good stop' trials it takes more time for the point-of-view to reach the blackout distance (100m or 50m) than during 'collision' trials. In order to reduce the confound between outcome of the approach (i.e., collision or good stop) and the time taken to complete each trial, two additional variables were manipulated during the experiment. Firstly, good stops and collisions of various kinds (and associated rates of deceleration) were simulated. In particular, there were four of each included in the experiment, involving self movement that would stop either 10, 20, 30, or 40m before (i.e., good stop) or after (i.e., collision) reaching the aft end of the ship's flight deck. Secondly, two different initial velocities were simulated; 40 and 60 kts. By factorially crossing these variables with the others described above, variability was introduced into trial time (trials took between 10.1 sec and 24.7 sec to complete) and the relationship between trial time and correct response was reduced to near zero (these variables shared less than 4% variance; point-biserial $r^2 = 0.039$).

In all, the experiment consisted of a 2 (lighting configuration) \times 2 (visibility) \times 2 (blackout distance) \times 2 (initial velocity) \times 8 (stopping location) within-subjects design. Participants in the non-expert group viewed two repetitions of each condition for a total of 256 trials. The expert viewed one repetition of each condition for a total of 128 trials. The experiment was completed in two sessions. The first took around 1.5 hours, the second around 1 hour. During the first session, participants were briefed on their task, viewed 16 practice trials with feedback and completed two blocks of experimental trials comprised of all conditions from one of the two levels of the 'visibility' variable (i.e., high or low visibility). During the second session, participants completed two blocks of all trials from the other level of the 'visibility' variable. The order of presentation of visibility conditions was counterbalanced across participants. No feedback was provided as to the correctness of responses during the experimental sessions.

3.2 Results

Data from the non-expert group are considered first in terms of participants' performance in identifying collisions and good stops, then in terms of their confidence ratings. Data from the expert participant are then considered as a case study for comparison with non-expert outcomes.

There are two possible strategies for examining the performance data from an experiment of this kind. The simplest strategy involves analysing proportion of correct responses (henceforth $P(c)$) in each condition to investigate performance. While this is a straightforward means of addressing hypotheses about participants' ability to perceive the difference between good stops and collisions it suffers from the shortcoming that it does not take into account response biases. For example, it does not allow examination of whether participants have a tendency or predisposition to respond one way or the other, or whether their criteria change across conditions. When no such biases are present, or when they are small, $P(c)$ represents a good estimate of performance. However, when significant biases exist, $P(c)$ underestimates participants sensitivity to differences between stimuli. The signal detection theory (SDT; e.g., MacMillan & Creelman, 1991) approach allows examination of both sensitivity to differences between stimuli (represented by the measure d') and response biases (represented by the measure c or criterion). Therefore, in order to expose the data to the most thorough analysis possible, an SDT strategy was adopted.

3.2.1 Non-Expert Performance Data

Sensitivity (d') to differences between good stop and collision trials and response biases (c) were calculated for each cell of the design for each participant. In accordance with the SDT scheme, responses were categorised as one of four types. Collision trials that were correctly identified were categorised as HITS. Collision trials that were incorrectly identified as good stops were categorised as MISSES. Good stop trials that were incorrectly identified as collisions were categorised as FALSE ALARMS. Good stop trials that were correctly identified as good stops were categorised as CORRECT REJECTIONS. Sensitivity (d') and response bias (c) were calculated according to the formulae below (Azzopardi & Cowey, 1997; MacMillan & Creelman, 1991) where the hit rate and false alarm rate are expressed as standardised scores (z scores):

$$d' = [z(\text{HIT}) - z(\text{FALSE ALARM})]$$

$$c = -[z(\text{HIT}) + z(\text{FALSE ALARM})]/2$$

The former yields a score which positively indexes sensitivity to differences between stimuli (i.e., participants' ability to discriminate between collisions and good stops). The latter yields a score which corresponds to participants' response biases, tendencies or criteria. In the present context, a positive value for c indicates a tendency to favour 'good stop' judgments, while a negative number indicates a tendency to favour 'collision' judgments. Both d' and c are expressed in units of standard deviation (i.e., z-scores). Summary statistics for these measures across the levels of the four main effects of the design are presented in Table 1.

Table 1. Mean values of d' (sensitivity) and c (bias) across levels of the main effects of the experimental design for the non-expert group.

		d' (std error)	c (std error)
Lighting Configuration	Point lights	1.37 (0.12)	-0.17 (0.19)
	DELs	1.39 (0.13)	-0.22 (0.16)
Visibility	Low	1.40 (0.19)	-0.18 (0.15)
	High	1.36 (0.19)	-0.22 (0.22)
Blackout Distance	100m	0.74 (0.18)	0.26 (0.21)
	50m	2.02 (0.11)	-0.66 (0.16)
Initial Velocity	40kts	1.27 (0.16)	0.97 (0.19)
	60kts	1.49 (0.10)	-1.36 (0.17)

Differences between sensitivity and bias measures across conditions were analysed using a pair of 2 (lighting configuration) \times 2 (visibility) \times 2 (blackout distance) \times 2 (initial velocity) repeated measures analyses of variance (ANOVAs; i.e., one for each dependent variable). A significant difference was found on sensitivity between 100m and 50m blackout conditions ($F(1,9) = 36.89, p < 0.001$). The nature of this difference was that participants were more sensitive to the difference between collisions and good stops when the view was blacked out at 50m from the ship ($M = 2.02$) than when the view was blacked out at 100m from the ship ($M = 0.74$). No other significant main effects or interactions were found in the analysis for sensitivity. It is of particular note that the difference between point lights and DELs was small and not statistically significant.

In the analysis of response bias significant main effects were found for blackout distance ($F(1,9) = 24.88, p < 0.05$), and initial velocity ($F(1,9) = 200.15, p < 0.001$). Participants favoured good stop judgments when blackout was further from the ship ($M = 0.26$) or initial velocity was relatively slow ($M = 0.96$), while they favoured collision judgments when blackout was closer to the ship ($M = -0.65$) or initial velocity was relatively fast ($M = -1.36$). A significant two-way interaction was revealed between blackout distance and visibility ($F(1, 9) = 16.38, p < 0.05$) and a significant three-way interaction was revealed between blackout distance, visibility and lighting system ($F(1, 9) = 14.76, p < 0.05$). The higher-order of these effects is depicted in Figure 4.

In 100m blackout conditions, there was a large bias in favour of 'good stop' judgments for low visibility, but virtually no bias for high visibility. The pattern of bias was different for 50m blackout conditions. In all 50m conditions, there was a bias towards 'collision' judgments. However, for point-source lighting systems this bias was smaller for high visibility than low; whereas for DELs the bias was more or less equivalent across levels of visibility.

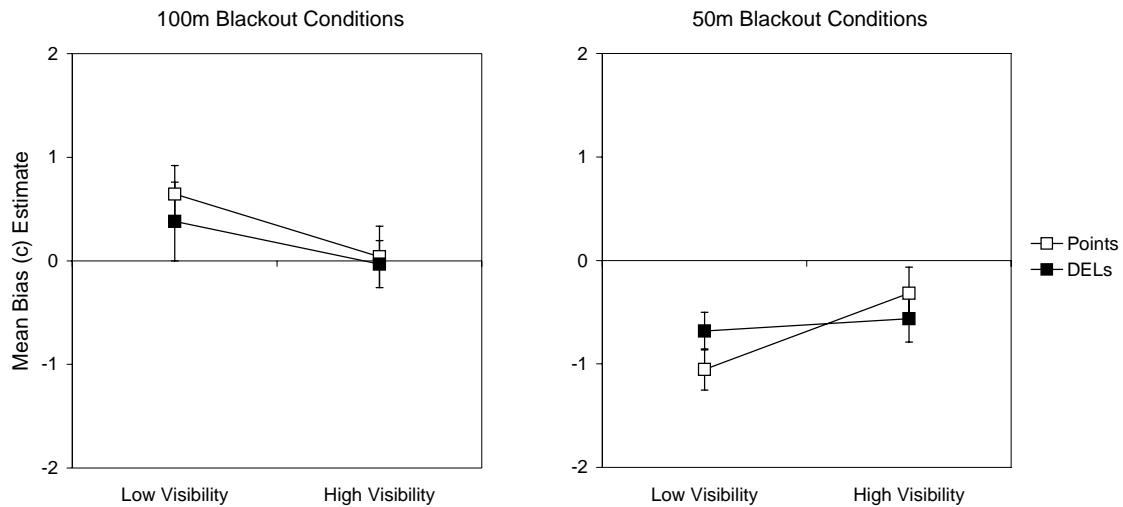


Figure 4. Plot of the significant three-way interaction between blackout distance, visibility and lighting system. Displayed values are mean bias (c) with standard errors.

3.2.2 Non-Expert Confidence Data

The average confidence rating for the non-experts across all conditions was $M = 3.54$. Differences in mean confidence ratings (between 1 = not at all confident and 5 = extremely confident) between conditions were analysed via repeated measures ANOVA. This analysis revealed many small but significant effects. The highest order significant effects are plotted in Figure 5 below. Participants reported significantly higher confidence in 50m blackout conditions ($M = 3.79$) than 100m blackout conditions ($M = 3.29$; $F(1,9) = 42.77$, $p < 0.001$). Participants were also more confident in their judgments in 60kts initial speed conditions ($M = 3.65$) than in 40kts conditions ($M = 3.42$; $F(1,9) = 6.97$, $p < 0.05$). There were a number of significant interactions. The highest order significant interactions were a three-way interaction between blackout, speed and visibility ($F(1, 9) = 7.73$, $p < 0.05$) and a significant three-way interaction between blackout, lights and visibility ($F(1, 9) = 8.11$, $p < 0.05$).

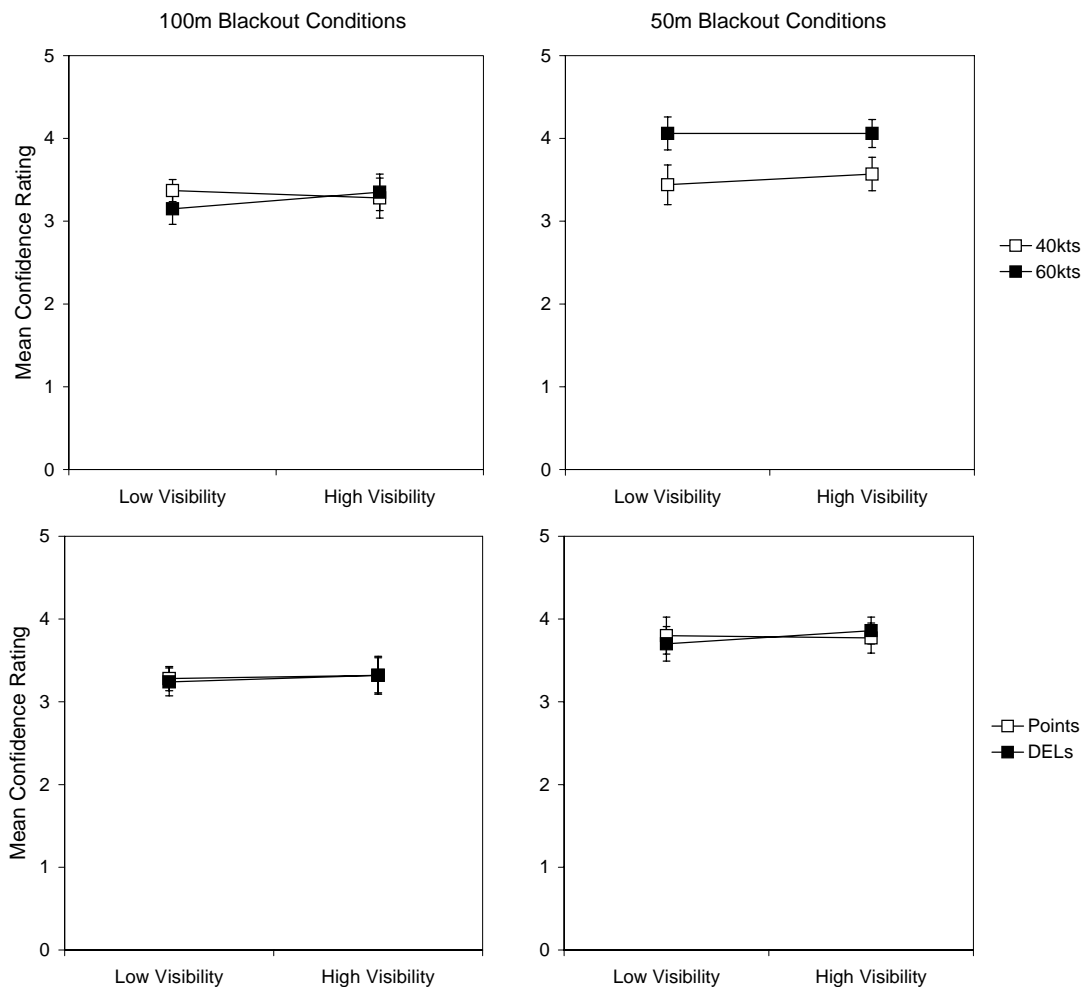


Figure 5. Plots of the significant three-way interactions between blackout condition, visibility and initial velocity (top row) and between blackout condition, visibility and lighting system (bottom row) for mean confidence ratings.

From the plot of the significant three-way interactions between Blackout, Visibility, and Initial Velocity (top row of Figure 5) and between Blackout, Visibility, and Lighting System (bottom row of Figure 5) it can be seen that there was little difference in confidence ratings across levels of the interaction involving lighting systems. The three-way interaction involved only a slight reversal in the order of scores in the 50m Blackout condition (bottom right panel). Greater differences were present between conditions in the interaction involving initial velocity. Participants were generally more confident in their judgments for high initial velocities than low for the 50m Blackout conditions (top right panel). However, in 100m Blackout conditions there was only a clear difference between initial velocities under Low visibility conditions; participants were slightly more confident in their judgments when initial velocity was low than when it was high (top left panel). Bivariate correlations between d' and confidence for each of the conditions of the experiment averaged $r = 0.09$. None of these correlations were statistically significant.

3.2.3 Expert Performance Data

Since only four observations were made in each cell of the design for the expert, SDT measures were judged undesirable for assessing the expert's performance. As a means of assessing the accuracy and bias in the expert's data, responses were plotted in the form of number of correct responses and number of 'collision' responses in each condition. The former is associated with the expert's ability to discriminate between collisions and good stops and can therefore be compared to the non-expert group's d' data. The latter is associated with the expert's response tendencies (since half the trials in each condition were collisions and half good stops) and can therefore be related to the group's bias (c) data. These data are presented in Figures 6 and 7 below.

The expert's responses mirrored those of the non-expert group in a number of ways. From Figure 6 it can be seen that the expert's ability to discriminate between collisions and good stops was greater when the view was blacked out close to the ship (50m; $M = 5.75$) than when it was blacked out far from the ship (100m; $M = 4.75$). There was also evidence of some biases in the expert's data. In particular, the expert paralleled non-experts in favouring 'collision' responses when initial velocity was high (60kts), and 'good stop' responses when initial velocity was low (40kts).

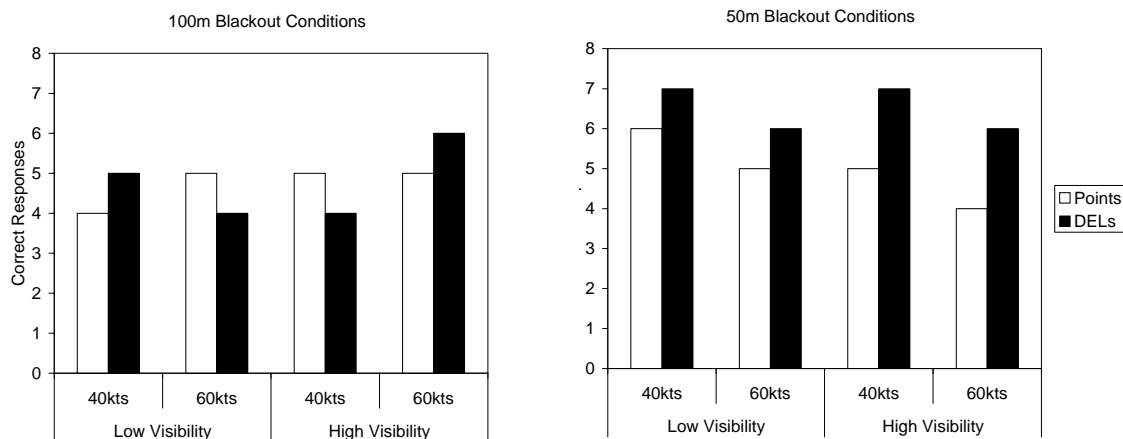


Figure 6. Data from the expert observer plotted as a function of proportion of correct collision and good stop judgments.

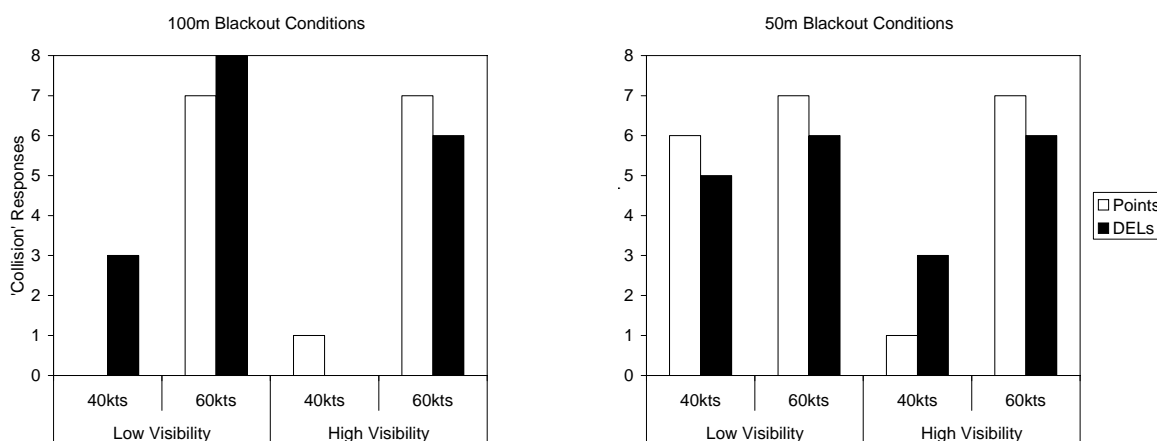


Figure 7. Data from the expert observer plotted as a function of 'collision' responses. Half of the trials in each condition were actually 'collisions' and half were actually 'good stops'.

Unlike the non-experts, there was a suggestion of a slight performance advantage for DELs over a point-source lighting system for the expert observer. The expert's accuracy was better for DELs than point lights in six of the eight conditions displayed in Figure 6. Also, for 50m blackout, high visibility conditions, there was a relatively large proportion difference in correct responses between DELs and point lights (right panel). However, interpretation of this evidence should be tempered by the fact that the performance differences between lighting systems shown in Figure 6 only involve two responses at most.

3.2.4 Expert Confidence Data

The average confidence rating for the expert participant across all conditions was higher than that of the non-experts at $M = 4.45$. The expert's confidence ratings are displayed in terms of mean confidence for the different conditions of the experiment in Figure 8 below.

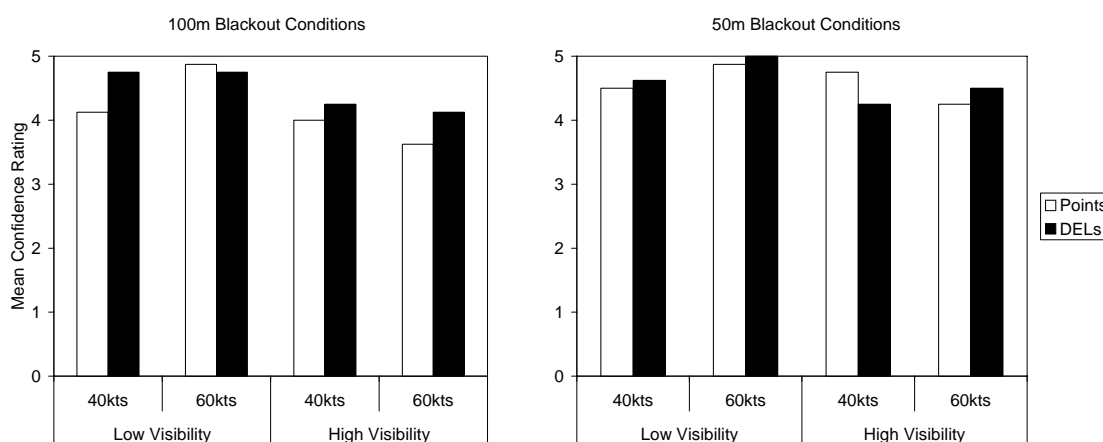


Figure 8. Mean confidence rating data from the expert observer.

As was the case for the non-experts, the expert participant appeared to be slightly more confident in 50m blackout conditions ($M = 4.59$) than 100m blackout conditions ($M = 4.31$). Unlike non-expert participants, the expert's confidence was about the same for both initial velocities ($M = 4.41$ and $M = 4.50$ for 40kts and 60kts conditions respectively). Across all conditions the expert's confidence scores were not closely associated with his accuracy scores; the correlation between these two variables was $r = 0.12$ (not statistically significant).

4. Experiment 2: Perception of Relative Position

The results from Experiment 1 show no clear effect of manipulations of ship lighting on perception of rate of closure during simulated approach to recovery. While the lighting system factor (point-lights versus DELs) was involved in a significant three-way interaction in the analysis of bias (between blackout distance, visibility, and lighting system; see Figure 5), the nature of this effect was not such that any clear benefit or cost can be attributed to either lighting system. What's more, there was no effect of lighting on confidence.

Although these results failed to provide support for the claimed benefits of DELs for aircrew visual perception, the conditions of Experiment 1 relate to just one aspect of perceptual performance during recovery; that of perceiving one's rate of approach. Other potential benefits of the DEL system have also been highlighted in previous research. Important amongst these is that during recovery the DEL system provides aircrew with enhanced perception of the position of their aircraft relative to the ship. This claim is apparent in evaluations cited by Tate (1995), who reported that with DELs "pilots were able to rapidly assimilate their relative position to the ship" (p.249), that "[pilots were] all immediately aware of the ease in which they could assess position, attitude, and rate cues" (p.254), and that the DELs were responsible for "greatly improving the pilots perception of position in relation to the ship" (p.248).

Veridical perception of spatial layout, including the size, shape and distance of objects from one another and oneself depends on detection of optical *structure* in the visual array. This structure is provided by optical discontinuities such as edges and textures. Generally, the abundance of such structure is positively related to the accuracy of perception of spatial layout (Cutting & Vishton, 1995). As noted by Gibson (1979), veridical perception of the layout of the world also provides for perception of one's position and motion relative to those objects: In his words, "information about a world that surrounds a point of observation implies information about the point of observation that is surrounded by a world. Each kind of information implies the other." (p.75). A clear example of the reciprocity that Gibson described between perception of the world and perception of the self can be found in the context of helicopter deck landing. The term *ship aspect* refers to the orientation of a ship as viewed from a particular viewpoint. As demonstrated in Figure 9, when a ship (or any other object for that matter) is viewed from different locations, its image as projected to the viewer is different. The view of the ship that is presented to the observer therefore specifies the observer's position relative to the ship.

While Figure 9 demonstrates this fact for viewpoints separated in azimuth, the same is of course true for viewpoints separated in elevation.

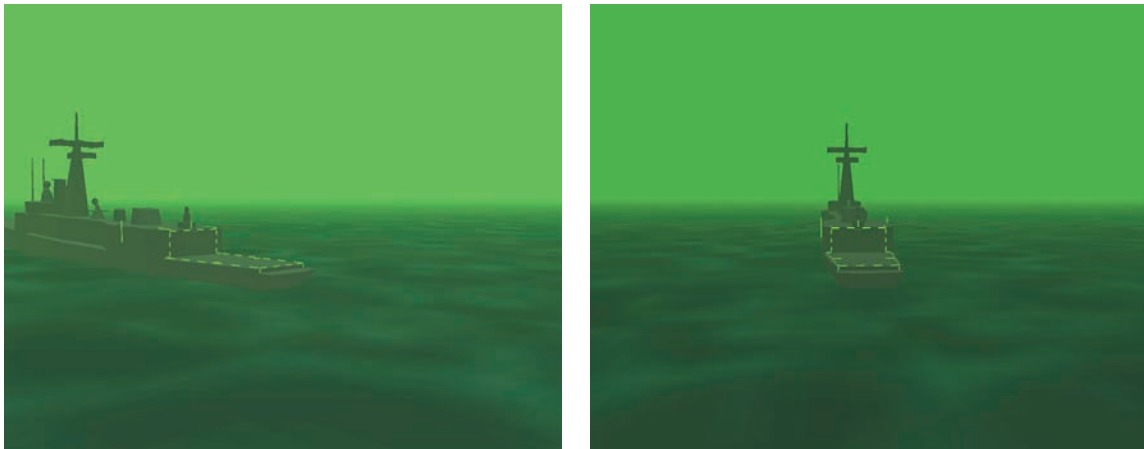


Figure 9. *Two different views of a ship model with DELs fitted to the flight deck and hangar. Ship aspect refers to the view of the ship obtained from a particular viewing position. The aspect of the ship projected to a given point of view specifies the location of the observer relative to the ship. As was the case for the stimuli in Experiment 2 the views depicted above are taken from different azimuthal positions around the midpoint of the aft end of the ship's flight deck.*

Experiment 2 was designed to investigate the possibility that the additional visual information provided by DELs could enhance perception of position relative to the ship, using similar methods to those used in Experiment 1.

4.1 Method

4.1.1 Participants

Participants were 10 adult members of staff of the Air Operations Division, DSTO, Melbourne. This group consisted of five males and five females, all of whom were considered non-experts in the fields of rotary-wing aviation and deck landing. All participants had normal or corrected-to-normal vision.

4.1.2 Procedure

As described above and depicted in Figure 2 four basic classes of stimuli were included in Experiment 2, formed by factorial combination of visibility (high versus low) and lighting (point lights versus DELs). Each trial consisted of an initial viewing phase of 5 sec, a 1 sec blackout, and a response phase which was not timed. During the initial viewing phase, the participant was shown a stationary view taken from one of 20 azimuthal positions around the midpoint of the aft end of the flight deck of the ship. The 20 positions were defined by factorial combination of 45, 35, 25, 15, and 5 deg offset left and right of the midpoint of the aft end of the flight deck, and distances of 100m and 150m from that point.

After the initial viewing phase the screen went blank for one second, then the response phase began. During the response phase the sea surface reappeared, having been rotated by a random amount (between zero and 360 deg) relative to the initial viewing phase. The rotation of the sea surface was to avoid the possibility of participants using parts of the sea texture as landmarks when making their responses (response task described below). However, the ship model was removed during the response phase and was replaced with a red dot which marked the location of the centre of the aft end of the ship's flight deck. The participant's task was threefold: Initially, they were asked to view the scene, noting the position of the simulated point of view relative to the ship. Then, after the view had been blacked out and the response phase had begun they were asked to make two responses. Firstly to move the point of view left or right, in 1 deg increments, around an arc centred on the red marker dot using the arrow keys on the computer keyboard to bring their position directly behind the (now unseen) ship. Secondly to provide a rating of their confidence in their judgment on a scale of 1-5 (1 = not confident at all, 5 = extremely confident). The dependent measure extracted from the position judgment was the angular distance in degrees between the ship's true centreline and the position judged by the participant to be directly behind the ship (note that when using this measure, accurate performance yields small scores). Both angular error and confidence ratings were recorded electronically for later analysis.

In all, Experiment 2 consisted of a 2 (lighting configuration) x 2 (visibility) x 2 (distance) x 2 (side) x 5 (angular deviation from centreline) within-subjects design. The experiment was completed in two sessions. The first took around 1.5 hours, the second around 1 hour. During the first session, participants were briefed on their task, viewed practice trials with feedback, and completed one block of experimental trials comprised of all conditions from one of the two levels of the 'visibility' variable (i.e., high or low visibility). Practice trials were conducted with high visibility. One practice trial was shown for each lighting configuration x distance x angular deviation x side combination (40 practice trials in all). During the second session, participants completed one block of experimental trials from the remaining level of the 'visibility' variable. The order of presentation of visibility conditions was counterbalanced across participants. During experimental blocks, participants viewed three repetitions of each condition for a total of 120 trials and no feedback was provided as to the correctness of responses.

4.2 Results

As in Experiment 1, the results are considered below first in terms of the accuracy of performance, then in terms of confidence ratings.

4.2.1 Performance Data

The root mean square error (RMSE) of responses from position judgements was calculated and analysed to determine the accuracy of participants' perception of position relative to the ship under the conditions described above. RMSEs from across the levels of the four main effects of the experiment are summarized in Table 2.

Table 2. Root mean square errors and associated standard errors of the mean across levels of the main effects of Experiment 2.

		RMSE (std error)
Lighting Configuration	Point lights	7.38 (0.43)
	DELs	7.27 (0.53)
Visibility	Low	7.59 (0.45)
	High	7.06 (0.51)
Blackout Distance	100m	7.22 (0.36)
	50m	7.43 (0.49)
Angular Deviation	5deg	3.98 (0.68)
	15 deg	5.89 (0.61)
	25deg	6.85 (0.66)
	35deg	8.64 (0.43)
	45deg	11.26 (0.89)

Differences between RMSEs across conditions were analysed using a 2 (lighting configuration) \times 2 (visibility) \times 2 (distance) \times 2 (side) \times 5 (angular deviation from centreline) repeated measures ANOVA. Only one statistically significant effect was found; between angular deviation conditions, with larger initial angular deviations leading to larger positioning errors ($F(2,15)=20.94$ $p<0.05$). This effect is displayed in Figure 10 below.

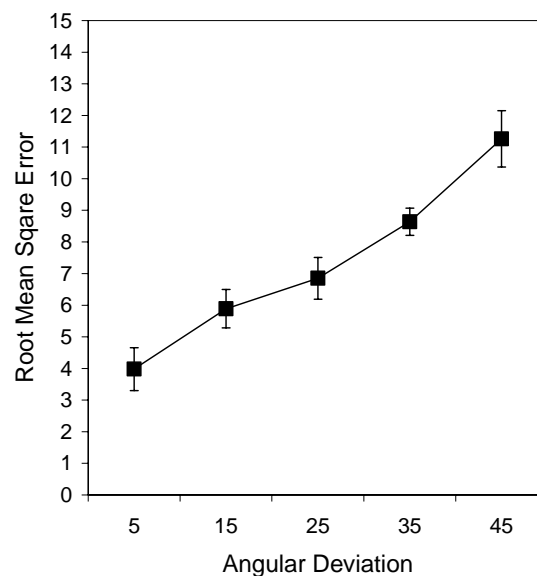


Figure 10. Plot of the significant main effect of angular deviation on position error in Experiment 2.

4.2.2 Confidence Data

The average confidence rating for the group across all conditions was $M = 3.35$. Differences in mean confidence ratings (between 1 = not at all confident and 5 = extremely confident) between conditions were analysed via repeated measures ANOVA. This analysis revealed two statistically significant effects; a significant main effect of angular deviation ($F(1,10)=23.48$ $p<0.05$) and a significant two-way interaction between lighting and angular deviation ($F(4,36)=5.62$ $p<0.05$). These effects are plotted in Figure 11 below.

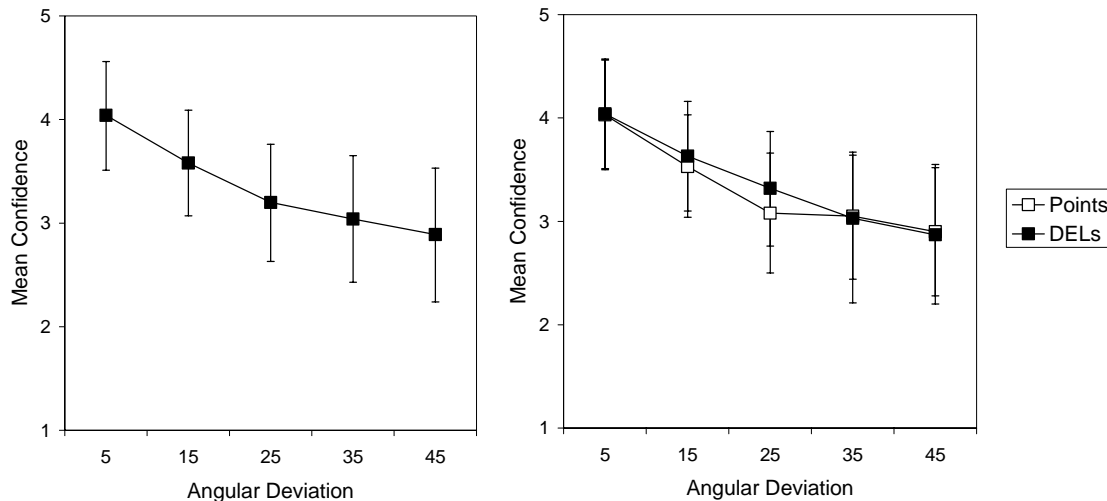


Figure 11. Plots of the significant main effect of angular deviation (left panel) and significant two-way interaction between lighting system and angular deviation (right panel) on position error in Experiment 2.

From the plots of the significant effects in the analysis of confidence data it can be seen that the most important difference in confidence ratings was across levels of initial angular deviation. Participants were generally more confident in their judgments for small initial angular deviations than for large. While this held for both point lights and DELs, the nature of the two-way interaction involving lighting conditions was that participants were slightly more confident in their judgments when DELs were present for some intermediate angular deviations. When angular deviation was either relatively large or relatively small, there was little difference between the lighting systems in terms of confidence. Bivariate correlations between RMSE and confidence for each of the conditions of Experiment 2 were predominantly negative (indicating that higher confidence was associated with lower positional error) and while quite small, were somewhat larger than those in Experiment 1, averaging $r = 0.25$. However, only two of these correlations were statistically significant.

5. General Discussion

The purpose of the experiments reported here was to investigate whether there are any specific perceptual advantages of a system of deck-edge lights (DELs; see Figure 1) over a system of point lights such as those currently in use by the RAN for night helicopter

operations. While the two experiments reported here do not represent a comprehensive investigation of this issue, it has been possible to isolate and evaluate two particularly important visual tasks in helicopter deck landing; perceiving the sufficiency of deceleration in order to time and regulate braking behaviours during approach, and perceiving one's instantaneous position relative to the ship. This represents an advance over previous research on the potential advantages of DELs, in which subjective rating scale data comprised the bulk of the evidence in favour of the new lighting system. Such data could be subject to many influences, including novelty, which may have led aircrews to positively evaluate DELs simply due to their inexperience with that relatively new ship lighting system.

Participants in Experiment 1 were asked to judge the outcome of approaches to recovery which varied in their rates of deceleration. Both expert and non-expert participants were better able to perceive the difference between rates of deceleration that were sufficient to stop them before reaching the ship and those that were not sufficient to do so when their view of the approach was blacked out 50m from the ship than when it was blacked out 100m from the ship. This provides empirical support for the concerns expressed by Smallhorn and Matthews (2000) following flight trials of NVGs. Those authors commented on the difficulty aircrew experienced in judging closure rate until they were quite close to the ship when approaching at night using NVGs. While the stimuli in these experiments bore a superficial resemblance to NVG imagery, no attempt was made to faithfully replicate the optical characteristics of those devices. In many ways the stimuli used here afforded the observer a better view of the world than NVGs; for example the images were free of blur and NVG scintillation. The finding that observers still had difficulty judging the sufficiency of deceleration when far from their target replicates previous research (Andersen et al, 1999) and indicates that while this problem may be exacerbated through the use of night-vision equipment, it is not likely to be a unique feature of their use. That is, the inability to perceive the adequacy of deceleration during early approach is likely to be a more general perceptual effect. This effect is possibly related to the non-linear nature of the expansion of object images which occurs during approach. While the images of approached objects grow in size during the entire approach, they do so at a very slow rate initially, only growing rapidly (indeed explosively) when the observer is quite close. Different rates of approach will result in characteristically different retinal-image expansion profiles. The optical properties of expanding images known as *tau* and *tau-dot* are invariant, meaning that in principle they are informative about the timing of collisions and regulation of braking behaviours across all object sizes, closing speeds, and distances. However, data from this experiment suggest that early in the approach when expansion rate is slow (and change in expansion rate is also slow), differences between expansion profiles are difficult to detect. For this reason, observers may have difficulty in using these sources of information until late in the approach. The implication of this finding is that an instrumental or procedural solution is likely to be required.

As well as affecting sensitivity to collisions and good stops, some approach parameters led to bias in participants' judgments. When the approach was blacked out relatively far from the ship (100m), or when the initial velocity was relatively slow (40kts) participants had a tendency to favour 'good stop' responses. The opposite was true of 50m blackout conditions and 60kts initial velocity conditions, in which participants tended to make more 'collision' judgments. These biases in participants' responses provide further evidence of

relatively poor perception of the adequacy of deceleration during approach, in that participants were strongly influenced by factors other than the sufficiency of deceleration in making collision and good stop judgments.

The influence of the factors listed above was neither attenuated nor strengthened by the inclusion of DELs on the ship towards which approach was simulated. That is, with regard to perceiving upcoming collisions and good stops, manipulations of ship lighting (point lights versus DELs) had no clear effect. The lighting system factor was involved in a significant three-way interaction (between blackout distance, visibility, and lighting system; see Figure 4) in the analysis of bias. However, the nature of this effect was not such that any clear benefit or cost can be rightly attributed to either lighting system. The implication of this finding is that the extra perceptual information made available in the DEL system is unlikely to provide a significant benefit for the timing and regulation of braking behaviours during approach to recovery. This is a salient point, since in previous research on DELs aircrew were vociferous in their positive evaluations of the system; specifically mentioning the regulation of braking behaviours as an aspect of the recovery which was enhanced by the additional visual information furnished by DELs.

Experiment 2 was designed to investigate a second purported perceptual benefit of the DEL system – that of enhanced perception of position relative to the ship. Results from this experiment paralleled those of Experiment 1 in that they revealed no performance advantage for the DEL system over a point-light system in terms of perceiving one's position relative to the ship. While the lighting system factor was involved in one statistically significant two-way interaction (between angular deviation and lighting system; see Figure 11), this effect was not indicative of any substantial advantage for the DELs.

It is possible that differences between the particular DEL and point light systems used in previous research and those simulated here led to differences in research outcomes. However, if the effect of the systems simulated in these experiments is assumed to be representative of the likely differences between DEL and point-light systems in general, the discrepancy between the findings reported here and the subjective evaluations of the aircrew given in previous research can be taken to highlight the importance of controlled experimentation as a adjunct to high fidelity simulation and flight trials. In these experiments, participants were asked to provide; (i) perceptual judgments, and (ii) ratings of their confidence in each judgment that they made. This enabled an examination of the relationship between performance on the perceptual judgment tasks and subjective experience of performance. A small amount of evidence in favour of an association between performance and confidence was found. In Experiment 1 participants were generally more sensitive to the difference between collisions and good stops and more confident in their responses in 50m than 100m blackout conditions. In Experiment 2 participants were both more confident and more accurate as initial angular deviation grew larger. However, this was the entire extent of the relationship between performance and confidence. For both expert and non-expert participants, there was virtually no correlation between accuracy in judging collisions and good stops and confidence in those judgments across different conditions of Experiment 1. In simple terms, for a given blackout distance (i.e., either 100m or 50m), participants were just as likely to be confident in an incorrect judgment as they were in a correct judgment. While correlations were somewhat larger in

Experiment 2, and some were even statistically significant, they were still small by standard criteria. The average correlation of less than 0.3 reflected less than 10% shared variance between the accuracy of perceptual judgments and confidence ratings for the relative position task.

The lack of a strong relationship between perceptual judgments and subjective ratings of performance in these experiments indicates that participants had little insight into their own perceptual performance. This implies that extreme caution should be exercised when interpreting subjective ratings in place of data more directly related to perceptual functioning, as has been done in previous investigations of DEL systems (e.g., Tate, 1995). The ability to dissociate perceptual performance and participants' subjective evaluations of their performance is a clear benefit of the kind of controlled experiments that are reported here.

While no performance advantage has been found for DELs over a standard point light system for judging relative position or the adequacy of deceleration during approach in this laboratory study, more research is needed. The research reported here should not be taken to represent a comprehensive investigation of the potential benefits of DELs for night helicopter operations. These experiments concentrated on distances and velocities typical of the approach phase of the recovery and were targeted at perceptual issues raised by earlier researchers and aircrew in the context of giving subjective evaluations of the DEL system. The DEL system may well have perceptual benefits that are not obvious under introspection and which could have led to the positive evaluations reported in previous research. These include better perception of aspects of self movement, such as direction of heading and altitude, as well as aspects of ship motion, such as pitch, roll, yaw and ship heading. Aspects of the landing phase are also important and deserve investigation. Though perception of rate of closure and relative position during approach do not appear to be aided by DELs under the conditions simulated here, conclusions regarding these other issues and about the overall potential of this system of ship lighting should be reserved until further investigations are completed.

6. References

- Andersen, G.J., Cisneros, J., Atchley, P., & Saidpour, A. (1999). Speed, size, and edge-rate information for the detection of collision events. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 256-269.
- Azzopardi, P., & Cowey, A. (1997). Is blindsight like normal, near-threshold vision? *Proceedings of the National Academy of Sciences*, 94, 14190-14194.
- Best, C. J., Day, R.H., & Crassini, B. (2003). The influence of object-image velocity change on perceived heading in minimal environments. *Perception and Psychophysics*, 65, 1273-1284.
- Bootsma, R.J., & Craig, C.M. (2003). Information used in detecting upcoming collision. *Perception*, 32, 525-544.
- Cutting, J.E. (1986). *Perception with an Eye for Motion*. Boston: Houghton Mifflin.
- Cutting, J.E., & Vishton, P.E. (1995). Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In W. Epstein & S. Rogers (Eds.). *Perception of Space and Motion* (pp 69-116). Sydney: Academic Press.
- DeLucia, P.R. (1991). Small near objects can appear farther than large far objects during object motion and self motion: Judgments of object-self and object-object collisions. In P.J. Beek, R.J. Bootsma, & P.C.W. van Wieringren (Eds.), *Studies in Perception and Action: Posters presented at the Sixth International Conference on Event Perception and Action* (pp. 94-100). Amsterdam: Rodopi.
- DeLucia, P.R. (1995). Effects of pictorial relative size and ground-intercept information on judgments about potential collisions in perspective displays. *Human Factors*, 37, 528-538.
- DeLucia, P.R., & Warren, W.H. (1994). Pictorial and motion-based depth information during active control of self-motion: Size-arrival effects on collision avoidance. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 783-798.
- DeLucia, P.R., Tresilian, J.R., & Meyer, L.E. (2000). Geometrical illusions can affect time-to-contact estimation and mimed prehension. *Journal of Experimental Psychology: Human Perception and Performance*, 26, 552-567.
- Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.
- Gray, R., & Regan, D. (1999). Motion in depth: adequate and inadequate simulation. *Perception and Psychophysics*, 61, 236-245.

- Kaiser, M.K., & Hecht, H. (1995). Time-to-passage judgments in nonconstant optical flow fields. *Perception and Psychophysics*, 57, 817-825.
- Kim, N., Turvey, M.T., & Carello, C. (1993). Optical information about the severity of upcoming contacts. *Journal of Experimental Psychology: Human Perception and Performance*, 19, 179-193.
- Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, 5, 437-459.
- Lee, D. N., & Reddish (1981). Plummeting Gannets: A paradigm of ecological optics. *Nature*, 293, 293-294.
- MacMillan, N.A., & Creelman, C.D. (1991). *Detection Theory: A User's Guide*. Sydney: Cambridge University Press.
- Royden, C.S., Banks, M.S., & Crowell, J.A. (1992). The perception of heading during eye movements. *Nature*, 360, 583-585.
- Sekuler, R., & Blake, R. (1994). *Perception*. Sydney: McGraw-Hill.
- Smallhorn, C.J., & Matthews, C.M. (2000). *Evaluation of the AN/AVS-6 night vision goggles for S-70B-2/FFG embarked operations*. Royal Australian Navy Formal Report 00/22.
- Stone, L.S., & Perrone, J.A. (1997). Human heading estimation during visually simulated curvilinear motion. *Vision Research*, 37, 573-590.
- Tate, S.J. (1994). *Flight trial evaluations of the benefits and practical problems associated with use of night vision goggles for recovery of helicopters to small ships*. DRA Customer Report DRA/AS/MSD/CR94118/1.
- Tate, S.J. (1995). *The development and application of novel visual aids to increase operational limits at the helicopter/ship dynamic interface*. Proceedings of the American Helicopter Society 51st Annual Forum, Fort Worth, TX, May 9-11.
- Tresilian, J. R. (1991). Empirical and theoretical issues in the perception of time to contact. *Journal of Experimental Psychology: Human Perception and Performance*, 17(3), 865-876.
- Vincent, A., & Regan, D. (1997). Judging the time to collision with a simulated textured object: Effect of mismatching rate of expansion of object size and of texture element size. *Perception and Psychophysics*, 59, 32-36.
- Warren, W. H. (1995). Self-motion: Visual perception and visual control. In W. Epstein & S. Rogers (Eds.). *Perception of space and motion* (pp.263-325). San Diego: Academic Press.
- Yilmaz, E.H., & Warren, W.H. (1995). Visual Control of Braking: A test of the tau-dot hypothesis. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 996-1014.

Warren, R. (1976). The perception of egomotion. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 448-456.

Zalevski, A., Meehan, J., & Hughes, P. (2001). *Size Estimation with Night Vision Goggles*. DSTO Technical Report. DSTO-RR-0201.

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19. ABSTRACT Accurate perception of position and self-movement is a critical factor for many tasks in aviation; particularly low-level flight, take off and landing. An especially demanding task of this kind is that of deck landings for rotary-wing aircraft, which are often conducted during the night. During night operations, ship-based lighting is used to assist the aircrew and flight-deck staff in the conduct of take-off and landing. While reasonably effective, the lighting systems currently employed by the Royal Australian Navy (RAN) were not designed specifically with the aim of enhancing aircrew visual perception. In two experiments a deck-edge light (DEL) system which provides a richer visual cueing environment for the aircrew than traditional point-source lighting systems was investigated in terms of its potential benefits for aircrew visual perception. These experiments could reveal no clear performance advantage for DELs over standard point-source lights. In both experiments, participants were asked to make ratings of their confidence in their judgments. Only a very weak relationship was found between accuracy and confidence, suggesting that care should be exercised when subjective ratings are interpreted in place of performance data. Further investigation is required in order to understand the potential of DEL systems for enhancing the safety of night operations.					